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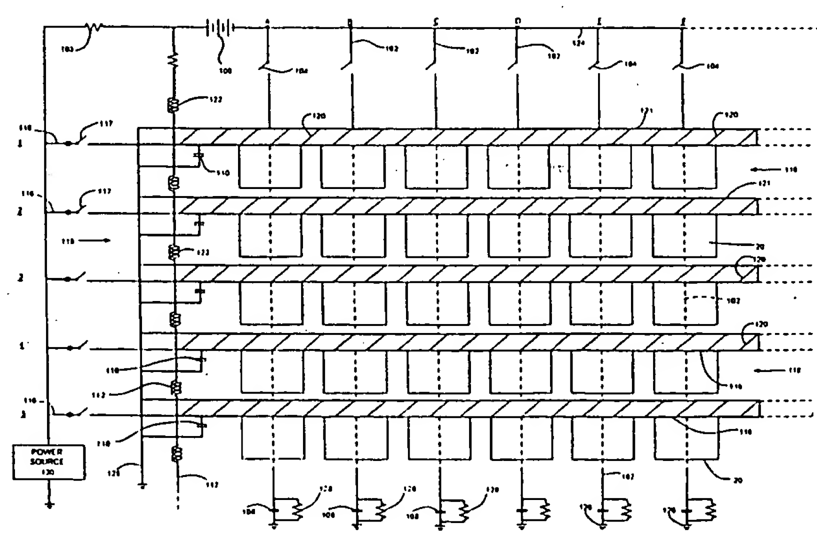
(57) Abstract

Disclosed are cross-talk resistant drive circuitry for electrostatic video displays and flexible, foldable and shaped embodiments of such displays including books, fanfolds and scrolls employing flexible polymer film construction. Transistorless drive circuitry uses row and column dumping capacitors (108) to charge electrostatic pixels (A1...F5) in a traveling group to avoid simultaneously charging row-adjacent pixels (A1...F5). Also, individual pixels (A1...F5) can be shielded each with their own Faraday cage (60–62) to control charge leakage from the pixel. The pixels (A1...F5)' have spiral rollout shutters whose time parameters can be controlled by the use of suitable bleed resistors. Low-cost film technology manufacturing methods are also described.



ELECTROSTATIC VIDEO DISPLAY DRIVE CIRCUITRY AND DISPLAYS INCORPORATING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electronically driven displays that can translate electrical signals into changeable static images or dynamic video images, and includes multicolor and full color displays. Such displays, or display screens, can comprise a pixellated screen formed by a multitude of individual, selectable state, light-modulating picture elements that can be controlled to provide text or graphic images. More particularly, the invention relates to electrostatic displays which employ capacitive pixels having light-modulating, movable electrodes that can adopt a number of positions, at least one of which is a position extending across the path of a light beam traveling through the pixel. By selective actuation of the movable electrode to interrupt the light beam to a greater or lesser extent, and to change the appearance of individual pixels, groups of such capacitive pixels in the display can be composed into meaningful images.

2. Description of Related Art Including Information Disclosed under 37 CFR 1.97 and 37 CFR 1.98

Kalt, or Kalt *et al.* U.S. Patents Nos. 5,638,084, 5,519,565 and 5,231,559 describe, *inter alia*, a number of capacitively driven, or electrostatic, pixellated video display inventions including, as disclosed in patent number 5,638,084, an indoor-outdoor multicolor display viewable by transmitted or reflected light. Each pixel of the display employs a movable electrode which, in preferred embodiments takes the form of a miniature metallized plastic coil or spiral while in a relaxed condition. Application of an electrical pulse between the coil and a fixed electrode located on the other side of a dielectric layer from the coiled movable electrode, (termed a "spiral rollout" herein), causes the coil to unfurl across the dielectric layer to modulate light rays striking the pixel, e.g. to block or reflect, them. In effect, the spiral rollout acts as a shutter for the pixel.

Such electrostatic, pixellated displays have advantages of low power consumption, low heat output, and low cost and in some embodiments, of being able to display brilliant reflective images that are viewable outdoors in daylight. Furthermore, preferred embodiments of such electrostatically driven displays are susceptible to mass production from suitably treated low cost

a risk that one or more pixel shutters will undesirably respond to a switching signal intended for an adjacent or nearby pixel. It would be desirable to provide suitable drive circuitry which were resistant to cross-talk, even when the display has very small pixels, e.g 0.01 inches (about 250 microns) or less.

The electrostatic displays described above are suitable for a variety of applications, for example, desktop and notebook computer screens, television receivers, conference room or assembly hall presentation screens, instrumentation displays, sports stadium displays (including "scoreboards" with video presentations) and outdoor signage, e.g. highway condition informational signs, as well as smaller personal informational display devices or computer "appliances" such as personal digital assistants, game-playing devices, Internet-enabled cellular phones and so on. Such devices, as they have been known prior to the present invention, because of the limitations of their underlying pixel technology, employ more or less planar or, in the case of cathode ray tubes, mildly curved, fixed form display screens mounted in protective structural frames. The curvature in cathode ray tube displays is usually considered undesirable, and being convex to the viewer, is visually inappropriate, but is more economical and practical for cathode ray technology than are flat-screen displays. Thus, conventional, commercially available displays provide physical restraints which limit the possible range of new devices that may be developed as display-utilizing technologies evolve. For example, a pocket-sized computer device with a form factor of say 8 inches by 4 inches (approximately 20 cm by 10 cm), yet which has a 9-inch (approximately 22.5 cm) diagonal screen is not believed possible with such commercially available displays. To the best of applicant's knowledge and belief, using conventional technology, the display area of such a device, even ignoring customary margins to the display area, can be no more than the form factor itself, namely, 32 in^2 (about 80 cm^2). Therefore, it would be desirable to provide a display which can be embodied in a device providing a display area in use which is larger than the form factor of the device in storage, the term "form factor" being used to reference the largest of the various possible two-dimensional projected profiles of the device.

SUMMARY OF THE INVENTION

The invention solves a problem. It solves the problem of providing an electrostatic display with drive circuitry which can drive high resolution displays with desirable refresh rates and which furthermore is resistant to cross-talk, especially in small pixel embodiments. This problem is

high resolution displays with desirable refresh rates, the invention provides in one aspect, an electrostatic display comprising:

a) an array of pixels each including a capacitively drivable electrode shutter movable between an open, light-transmitting position and a closed, light-blocking position and being mechanically retractable to a starting position; and

b) drive circuitry for the pixel array capable of applying control signals to selected pixels to move selected individual ones of the electrode shutters between their respective open and closed positions

wherein the drive circuitry is operable to charge each selected pixel in a relatively short charging interval and to discharge each selected pixel in a relatively longer discharging interval. Preferably, the ratio of the discharging interval to the charging interval is at least 5:1, more preferably at least 50:1 and still more preferably, at least 500:1. By employing a strongly asymmetrical charge:discharge cycle, the invention permits large numbers of pixels to be charged while others are discharging, enabling the complete array to be charged, or addressed for charging if so selected by suitable software drivers, in a small enough time slice, e.g. in 1/30, 1/60 second or less, to provide a desired refresh rate.

In a preferred embodiment of the invention, the drive circuitry effects charging by applying a short charging pulse to one or more pixels to be charged, the charging pulse having a pulse width determining the charging interval. Preferably the charging pulse is applied to a dumping capacitor servicing a group of pixels, for example a row or column of pixels, and the dumping capacitor is connected to charge each and every specified pixel in the pixel group on each refresh cycle. Because the charge interval is much shorter than the discharge interval and because no turn-off pulse is required to retract an extended electrode, the charging pulse need not be applied progressively to every designated pixel in the raster during each refresh cycle, but may jump around the display or be applied to one or more groups or rows of pixels in a spatially non-sequential manner, provided that all pixels designated for activation can be charged in a given refresh cycle.

Preferably, the drive circuitry further includes a number of bleed resistances for draining charge from the pixels and each pixel is connectable with one of said bleed resistances to drain charge therefrom. Furthermore, the value of each bleed resistance can be selected, in relation to the capacitance characteristics of the pixel, to determine the duration of the discharge interval. By

preferably being substantial, e.g. 10 or more, but being substantially less than or, at most, equal to the number of pixels in a row, so that specified row-adjacent pixels receive charging pulses at different times, whereby cross-talk is inhibited.

Effectively, the invention provides, in this aspect, a row-sequential charging system which reduces the risk of cross talk by avoiding simultaneously delivering a charging pulse to pixels with the same column address in adjacent rows, while avoiding the delays that would occur if the pixels were charged one at a time. However, some pixels at one end of one row may be charged at the same time as some pixels at the other end of an adjacent row are being charged, so long as there is no overlap with respect to the columns. Alternatively, the traveling pulse could be applied to the columns. It will be appreciated that for the purposes of the present invention, the rows and columns may be logically interchangeable, subject to the requirements of the video signal which usually scans horizontally. In either configuration, cross talk is avoided by the invention, by maintaining a spatial or temporal separation of pixels receiving a charging pulse so that the act of charging one, or more significantly, several adjacent pixels in one row, (or column) does not trigger a quiescent pixel in an adjacent row (or column respectively).

As an alternative to a row-sequential charging regimen, the pulse could jump around the raster being applied to different groups of pixels in turn according to a random or organized pattern. The ability to charge a pixel very quickly enables complex, randomized, or partially randomized, charging patterns to be employed wherein, for example, an individual pixel, or small group of possibly non-adjacent pixels in a first portion of the raster is pulsed, then left to unfurl while another pixel or group in a second portion of the raster, which may be remote from the first portion of the raster, is pulsed in its turn, and so on until the complete raster is addressed pursuant to the randomized or partially randomized pattern. It will generally be more convenient to repeat the pattern in each refresh cycle, but variations may be made as will be apparent to those skilled in the art. A suitable group size will also be apparent to those skilled in the art and may for example comprise from about 0.001 percent to about 5 percent of the total number of pixels in the display, preferably about 0.05 to about 1percent. If desired, the group can be an organized group, for example a geometric sub-unit of the complete display raster, for example a rectangle, triangle, hexagon or a complete row or column, and not all groups need have the same number of pixels or geometric character. To use illustrative language, the pulse can be

Thus, unlike other types of display, in an electrostatic display employing movable pixels, a biasing voltage can be used. For example, referencing a row-and-column display, each row of pixels can be supplied with a biasing direct current voltage to a value below or near a pixel activation threshold to reduce the required drive signal voltage.

The several aspects of the invention are well adapted to be embodied in displays wherein the pixels are organized in an orthogonal array and a half-select drive system is employed. In such displays, the fixed electrodes can be connected together in columns extending transversely of the pixel rows, preferably located behind the dielectric, from the viewer's perspective, while the movable electrodes are connected together in rows. The timing and level of the applied voltage are selected on a row-by-row basis so as to apply a proportion of the applied voltage, for example half, to columns with an active address and then to apply a desired complementary voltage to the row so that all pixels in the row with an active address are charged. To achieve the desired traveling pulse effect of the invention, it may be preferable first to apply the row voltage, and then to apply the column pulses in sequence as a traveling group moving from one end of the row to the other.

To facilitate the process of charging specified pixels, the drive circuitry preferably further includes a column dumping capacitor for each column of pixels and a drain resistor connected in parallel across the column dumping capacitor to leak charge across the dumping capacitor and drain static build up.

In preferred embodiments, the drive circuitry includes a power source and, for each row and transverse column of pixels, a clock switch to connect the row or column to the power source. If desired, the whole display can be enclosed in a Faraday cage to inhibit stray external electrostatic events from interfering with proper operation of the display.

Larger displays, such as those for a theater, sports stadium or outdoor arena, can be constructed as a large matrix divided into rectangular panels that are separately driven and electronically pasted together to generate a coherent image.

In another aspect, to solve the problem of providing a portable display device having a useful display area which is larger than its form factor (the device's largest projected profile or

coiled electrode has a small footprint in its retracted position compared with its extended position so that there is little passive or dead space within a display perimeter and the active pixel areas fill a high percentage of the occupied display area. For example, smaller spiral rollouts may have lengths 10 or more times their retracted diameters, while for larger rollouts the proportion may be 100 or more.

Other configurations of movable electrode suitable for operation in an electrostatic pixel will be apparent to those skilled in the art, or may be developed, for example equilateral triangular rollouts organized in hexagonal arrays and "flapper"-type pixels, the latter of which are known and have been utilized in outdoor displays.

BRIEF DESCRIPTION OF THE DRAWINGS

One way of carrying out the invention is described in detail below with reference to the drawings which illustrate one or more specific embodiments of the invention and in which:-

Figure 1 is a partial sectional view of one embodiment of a layered structure, flat, thin panel, video display comprising a raster of electrostatically actuated pixels;

Figure 2 is a circuit diagram partially illustrating an embodiment of display such as that shown in Figure 1, having novel drive circuitry employing a dumping capacitor and drain resistor for each row and column of the display raster to control the charging and discharging of specified pixels;

Figure 2A is a schematic circuit diagram of a portion of the embodiment of Figure 2, showing charging and discharging circuitry connected with a single pixel;

Figure 2B is a schematic plan view of a portion of a modified display construction showing a pixel rollout provided with a Faraday cage;

Figure 2C is a view on the line 2C-2C of Figure 2B;

Figure 3 is a schematic sectional view of a reflective mode electrostatic video display embodiment of the invention;

Figure 4 is a schematic sectional view of a transmissive-reflective mode electrostatic video display embodiment of the invention;

Figure 5 is a schematic perspective view of a vee-shaped display embodiment of the invention;

Figure 6 is a schematic perspective view of a fanfold display embodiment of the invention;

coating, to provide, or complete, a Faraday cage to protect against electrostatic interference. The volume in which electrodes 18 move can be evacuated, if desired, but this is not believed necessary in most embodiments. However, some degree of sealing against ambient conditions, or even evacuation, may be helpful in improving performance under humid conditions, since undue humidity may affect the electrostatic characteristics of one or more individual pixels. High value embodiments, or those intended for stringent conditions may have gas-tight, preferably moisture-resistant, seals, and may be evacuated, or filled with dry air or an inactive or inert gas, if desired.

One suitable transparent conductive material which can be used for the fixed electrodes in control layer 22, or for coating or providing cover 52, is indium tin oxide. Others will be known or become known to those skilled in the art, for example a proton-doped polyaniline material, such as disclosed in United States patents numbers 5,618,469 or 5,626,795.

Light traveling on a transmissive light path proceeds from back lighting 16 through color screen 24, through control electrode layer 22, and through matrix layer 18 to viewer 12. Light traveling along a reflective path proceeds as an incident ray, which is transmitted through matrix layer 18, and through control electrode layer 22 to a front surface 30 of color screen 24 where it is reflected (and possibly modulated, for example to color the light ray). The reflected ray is transmitted back through control layer 22, and through matrix layer 18, to the viewer 12.

Spiral rollouts 20, in matrix layer 18 are arranged so that when all electrodes are extended they form a flat open screen, for which purpose they are preferably colored or coated with a black colorant or coating material, for example, black ink to provide a uniform black display screen. Matrix layer 18 also incorporates a sheet of a transparent dielectric 32 of any suitable non-polar material, for example a polytetrafluoroethylene homopolymer or copolymer material, e.g. TEFLON (trademark DuPont), or polypropylene. Spiral rollouts 20 have a conductive, metallized electrode coating which is brought into contact with a front surface of transparent dielectric 32 when the spiral rollout is in an extended position. This metallized coating serves as a variable electrode having a contact area with dielectric 32 which changes in size as the electrode 20 coils and uncoils, varying the capacitance of the pixel.

Preferably, spiral rollouts 20 are plastic elements that are prestressed into coils or spirals. While

use of a biasing voltage is desirable, enabling the required row and column driving voltages to be within a range suitable for operation using commercially available integrated circuit drivers developed for conventional electroluminescent displays.

Since the release threshold voltage may be substantially lower than the activation threshold voltage, it is possible to bias the driving voltage to a point between the activation and release thresholds. However, a preferred operating mode, pursuant to the present invention, biases the applied voltage to a point sufficiently below the activation voltage threshold such that no pixel is activated inadvertently and then effectively removes the applied voltage, leaving the coiled electrode to retract in its own time, as its holding charge decays. To this end, the biasing voltage may lie in the range of 60 to 90 or 95 percent of the activation threshold, preferably 75 to 85 percent of the activation threshold voltage.

Employing the novel drive circuitry disclosed herein, such displays can be produced in embodiments that are readily multiplexible, that respond repeatedly to pulses as narrow as 2 microsecond, or less, in a repeatable matter with a very high turn-on to turn-off optical ratio.

The high degree of multiplexibility permits resolutions of the order of VGA to be embodied in flat panel displays covering a full range of devices from small portable applications with, for example 5 inch (12.5 cm) screens or smaller, for personal assistants and other information appliances to large command and control or HDTV applications with screens as large as 40 inches (100 cm) or greater.

Thus, high contrast, high-resolution multiplexed flat panel displays can be provided which, as compared with conventional active matrix and LCD displays, may have favorable costs and low power consumption. The pixel rasters of displays described herein can be formulated without use of semiconductor manufacturing processes and are therefore well adapted to production in larger sizes than the limitations of semiconductor manufacturing permit.

Desirable drive circuitry for the video display 10 should switch the shutters constituted by spiral rollouts 20 with a cycle time and accuracy sufficient to enable video display 10 to provide a high quality image, preferably a moving video image with a refresh rate of one-thirtieth (1/30) of a second or less. With regard to accuracy, it is important to avoid, or control, cross-talk, whereby

column feed line 124 and a column clock switch 104 is inserted in each column 102 to close the column circuit and apply power to each pixel in proper sequence, as required by the video signal. Resistance 103 is provided to maintain a potential difference between the rows and columns.

Preferably, a direct current biasing voltage is also supplied, for example as indicated by battery 100 with a value near to or just below the threshold activation voltage of the pixels. Power source 130 outputs a display drive signal with all necessary characteristics of voltage, pulse, phase, timing, and so on, that are required to actuate the display. Depending upon whether the application is analog or digital, suitable sync circuitry or software drivers are provided to interpret the video signal into appropriate drive signals for a particular embodiment of display, as will be apparent to those skilled in the art.

Suitable voltages will be apparent to those skilled in the art, or can be determined without undue experimentation. Generally, the lowest effective voltage will be preferred for reasons of economy of space and components, as well as safety. At a minimum, the voltage provided by power source 130 must be no less than the pixel activation threshold which depends upon the capacitance characteristics of individual pixels and the mechanical force required to uncoil a prestressed, coiled, spiral rollout 20, minus whatever biasing voltage is provided by battery 100, or other biasing voltage source, if present. The activation threshold will vary with the length of the rollout, i.e. the distance of excursion, and will vary inversely with the dielectric thickness. Substantially higher voltages than the activation threshold can be used, especially for devices connected to a building power supply providing a constant 120 volt or higher source, and will provide quicker roll out of the coiled pixel.. The modest power requirements of electrostatic devices facilitate management of such higher voltages as may be desired for particular applications.

The pixels are arranged in rows 118, labeled 1 through 5, of approximately square spiral rollout shutters shown in an unrolled condition (shutter closed). All pixels in a row 118 are connected to be electrically common to each other and to a row-dumping capacitor 110 which is provided at the left-hand end of each row 118 to assist in charging the pixels in each row 118. Columns 102 are similarly each provided with a column dumping capacitor 108 to which each pixel in the column 102 is connected. Capacitors 108 and 110 function as local charge reservoirs, accepting the initial charge rapidly from power source 130, storing the charge, and then dumping or

Drain resistors 128 can take any suitable form but are preferably thin-film distributed bleed resistors fabricated from a readily depositable material for example a quaternary ammonium salt-based material, such as that used to dissipate static charge on cloth material. Resistance of these materials is quite high but their conductivity is adequate to discharge static buildup (e.g. about 10^8 or 10^9 ohms/square). Drain resistors 128 can be embodied on a silicon chip by coating the chip with a suitable pattern of such resistive material.

Each pixel row 118 is supplied with power from source 130 by a feed line 116 controlled by a clock switch 117, and its row dumping capacitor 110 is grounded by ground line 126. A bleed coat is put down parallel to the rows, forming bleed resistor lines 120, to provide an impedance between each spiral rollout 20 at feed line 116, and ground, represented by a ground line 121. Bleed line 120 provides a small spatial separation between dumping capacitor 110 and feed line 116, on the one hand, and ground line 121, on the other hand. Bleed resistor line 120 can be formed of any suitable material to have performance characteristics such that the charge in any unfurled pixel in the row drains off with a very small current in approximately 10-30 milliseconds, more preferably about a thirtieth of a second, providing a lag which approximates the lag of the phosphors of a computer or television cathode ray tube, wherein the signal bleeds away in the time required for one frame. Thus, for an unfurled, electrode extended, pixel with a capacitance of, say, 10 pF (picofarad) selecting bleed line 120 to provide a resistance of about 3,300 megohm at each pixel will permit a charge-drain cycle to be completed on each frame of a 30 Hz refresh rate. A resistance of about 1,600 megohm will be appropriate for a 60 HZ refresh rate, and so on. If desired, for the purpose of reducing interference or cross-talk between adjacent pixels, resistor bleed line 120 can be divided by air gaps between adjacent pixels to provide individual pixel bleed resistors.

Typically, there is no negative pulse in the bleed-off of a video pixel as described in the preferred embodiments of the invention, simply an attenuation of the energy in the pixel capacitor over time. Reversal of polarity is not necessary: the voltage is either all negative or all positive.

Bleed line 120 is preferably a thin-film conductor of suitable resistance, for example, vapor-deposited aluminum or graphite, or a suitable quaternary ammonium salt, or a suitably resistive material which can be photo-etched into the circuit in a desired location, with precision.

through the pixel. If the pulse duration is high, the spiral shutter unrolls, extending across the pixel almost completely and blocking most or all of the light from passing through the pixel. The shutter is closed. If the pulse duration is low, the spiral shutter only extends partially, allowing some light to pass through or alternatively, may extend fully but retract earlier in its cycle. The pulse width may be determined either in the applied drive signal, or by varying the duration of closure of column clock switches 104.

Such controlled partial time or spatial extension of the pixel shutter enables the pixel intensity to be varied to provide tints, tones, half-tones or shades of gray. By giving the control electrodes in layer 22 a triangular or tapered shape of diminishing width in the direction of roll out, variations in amplitude of the applied voltage will also serve to control the extent of roll out and thence the intensity of the pixel. Such features are desirable for full color displays. However, in lower cost displays, especially monochrome displays employing high contrast pixel and background, for example, digital signs and automobile dash displays, a binary ,

Each spiral pixel is charged with the intended voltage and discharges energy across a bleed line 120. The charging pulse moves from left to right, like a train, from one spiral pixel to another along the row with a duration such that, at any given moment, a group of contiguous pixels along the row may be receiving charge (provided their addresses have been designated for switching by the software drivers). After a row 118 is charged, the remaining charge travels to the next row below, charging those spiral pixels one at a time, also from left to right, in the same manner as the previous row. The number of pixels in the charging group should be less than the number of pixels in a row, to avoid simultaneously charging row-adjacent pixels with the same, or an immediately neighboring, column address, which may cause cross-talk.

To ensure adequate time differentials, it is much more preferable that the number of pixels in the group, $P_{G,}$ be significantly less than the number of pixels, P_R, in a row, e.g. P_G should be no more than ninety, or preferably eighty percent of P_N or substantially less. A minimum value for P_G is two, but more useful values will be substantially higher, such as 10 to 50 up to about fifty or even sixty percent of P_R according to the desired refresh rate and charging circuit parameters, including the relevant pixel parameters such as capacitance and response times. Higher values of P_G are useful to reduce overall cycle times and thus enable increased refresh rates, but may be limited by the capabilities of row-dumping capacitor 110. Perhaps more importantly, higher P_G

and mix primary colors to give the appearance of natural color, matching a scene scanned by a camera or depicting motion as in a motion picture. In one example, employing pixel shutters with a maximum excursion of 10 millimeters, a charge pulse with a width of about 5 microseconds is applied to the dumping capacitor 110 and causes the spiral rollout 20 to extend fully in about 10 milliseconds, incomplete excursions for lighter color values being effected in less time. The short charge time of the dumping capacitors allows the circuitry to actuate spirals fast enough to cover the entire raster while each pixel's response time is slow enough to generate a full color picture on the capacitive matrix, which is acceptable to the human eye. The raster is charged at rates of thirty (30) frames per second or at another rate determined by broadcast equipment and settings. To speed up the rate of excursion, voltage can be increased.

In a preferred embodiment of the invention, the RC circuit functions to delay the application of the charging voltage across the appropriate dielectric during a period selected to enable a suitable group of pixels, e.g 15, to be charged. The selected group is horizontally contiguous but will travel from the end of one row to the beginning of the next. Each spiral pixel can be charged for a suitable period, e.g. 75 microseconds while the next 15 pixels in sequence also receive charge simultaneously from the dumping capacitor before the charge in the dumping capacitor has leaked off to ground.

In one example of a display according to the invention, comprising a raster of pixels about 0.1 inch (2.5 mm) square, having an active area of about 0.01 in^2 (about 6 mm^2) employing aluminum-coated polyester electrode spirals rolling out onto a 1.5 mil (about 400 micron) thick polypropylene dielectric with indium tin oxide control electrodes, and a small spiral rollout marginal anchor portion of about 1 to about 20 percent 3-10 percent of the area of the pixel, the capacitance can vary between about 0.2 pF (picofarad) in the coiled, retracted state (shutter open) and about 9 pF in the uncoiled extended state (shutter closed). Those skilled in the art will understand that the foregoing (and following) quantities are approximations and that considerable variations are possible within the scope of the invention. Thus, the capacitance of pixels of comparable area will vary according to the thickness and nature of the dielectric, and other factors. For pixels about 0.1 inch (2.5 mm) square, the capacitance may lie in a range of about 0.01 to about 5 pF, preferably about 0.05 to about 1 pF, in the coiled, retracted state and about 0.5 to about 500 pF, preferably about 1 to about 50 pF in the uncoiled, extended state of the electrode 20. Preferably, the proportion of capacitance in the uncoiled to the coiled state is at

pixel B3. In Figure 2A, it may be seen that the pixel's spiral rollout 20 (at its metallized surface) is series connected through clock switch 117 with power supply 130 while its respective control, in layer 22, is series connected through clock switch 104 with battery 100 and power source 130. Row dumping capacitor 110 is parallel-connected with the pixel via rollout 20 and ground, while column dumping capacitor is similarly parallel-connected with the pixel via ground and its fixed electrode. Bleed resistance 120, across row dumping capacitor 110, and drain resistance 128, across column dumping capacitor 108, complete the circuit elements for an individual pixel.

In the modified embodiment shown in Figure 2B, each individual pixel comprises a Faraday cage extending around the zone occupied by the pixel's spiral rollout 20 to shield the movable electrode and reduce cross-talk or cross-coupling between adjacent pixels, which may adversely affect the quality of the displayed image. Thus, Figure 2B shows a portion of a row of pixels constructed so that, in each case, fixed electrode 22 is a little larger than the spiral rollout 20, which is here shown in an extended position.

As shown, fixed electrode 22 is larger than rollout 20 and has a marginal zone around its periphery which extends laterally beyond the area of spiral rollout 20 with horizontal extensions 60 running between the rows and vertical extensions 62 running between the columns, so that all four sides of rectangular rollout 20 are shielded. Other configurations of rollout can be shielded by correspondingly shaped and dimensioned fixed electrodes 22 providing extended marginal zones along one or more sides or extensions of the rollouts excursion area, as will be apparent to those skilled in the art. The peripheral marginal zone constituted by extensions 60 and 62 of fixed electrode 22 provides a Faraday cage around the zone occupiable by rollout 20, shielding the rollout and preventing leakage of charge from the pixel.

The particular configuration of the electrode areas and the width of extensions 60 and 62 can be varied to obtain the desired result of controlling cross-talk between pixels, as may be determined with suitable but not undue experimentation. For example, noting that the anchor end 64 and free end 66 of rollout 20 have different mechanical characteristics from the side edges 68 of the rollout, which will provide different electrostatic characteristics, it may be desirable to vary the width of horizontal extensions 60, in relation to the width of vertical extensions 62, for example by making them larger if cross-talk is a problem. While the invention is not bound by any

If desired, the gaps between rollouts 20 that are implied by horizontal and vertical extensions 60 and 62 can be visually masked with for example, white or black lines, in any desired layer of the display between the rollout layer and the viewer. Some larger constructions of display may permit an insulating or poorly conductive separator element (not shown) to be laterally interposed between adjacent rollouts to provide desired masking, and to enhance control of cross talk.

An alternative way (not shown) of effectively providing a Faraday cage around a pixel or along desired edges of a pixel, is to render non-conductive an appropriate small peripheral marginal portion of the conductive surface of rollout 20 that faces dielectric layer 32 (in the case of metallized polyester, the metallized surface), either by removing the conductive material, or not applying it to such a small peripheral portion, or by coating it with a suitable insulator. This approach can reduce the optical spacing between adjacent pixels, but may entail manufacturing complications.

It will be understood that in cases where such pixel shielding measures are sufficiently effective, the traveling pulse technique of charging the raster of pixels may not be necessary to avoid cross-talk or cross-coupling. Thus the invention contemplates use of either a traveling pulse or pixel shielding or a combination of both innovations, to avoid cross-talk and provide satisfactory image quality, the particular method being selected according to the characteristics of a particular embodiment of display, which can be determined by experiment, if necessary.

Turning now to the behavior of an individual pixel and referring again to Figure 2A, in the quiescent state of pixel B3 spiral rollout 20 is coiled up into its retracted position, permitting light to pass through the pixel without interruption or modulation. The pixel is light transmissive. At the beginning of a row charging cycle, when the raster scan reaches any given row, row clock switch 117 closes, charging row dumping capacitor 117 and raising the potential of each spiral rollout 20 to the value of the applied signal. Switch 117 remains closed while a traveling group pulse moves sequentially along the row from column to column with a duration at each column such that, ignoring end effects, from about 10 to about 50 columns are being pulsed or charged at any given moment in the charge cycle. Only those clock switches 104 of those columns having a pixel address in the given row designated for activation by the video signal are closed. The timing and duration of closure of each clock switch 104 is selected to

one-thirtieth of a second within which to complete a charging cycle across the raster. When the performance of an individual pixel is considered, the electrical response times are negligible compared with the mechanical. However, the electrical characteristics should be tuned to enable a full raster scan to be completed on every cycle. For a pixel of the order of 0.1 in (2.5 mm) long a pixel excursion time in the range of about 1 to 10 milliseconds can be obtained, occupying a relatively small proportion of the available time slice. (The excursion time for a rectangular spiral rollout 20 can be expected to be largely independent of its width.) A few milliseconds, e.g 2-5, can be allowed for retraction of the rollout, with the electrical parameters being adjusted, pursuant to the teachings herein, to provide sufficient charge to hold the rollout 20 extended for the to balance of the time slice, about 20 ms, or a little less. Alternatively, if desired, the hold-down phase may be extended substantially to the end of the time slice, permitting retraction, if designated in the next refresh cycle, to occur at the beginning of the next cycle. Such phase overlap can improve image persistence and reduce rollout cycling, preventing oscillation of the spiral rollout 20 of a pixel designated for activation in multiple consecutive cycles. Most video images have only small changes between most frames.

Some possible specifications of displays of various sizes and resolutions are set forth in Table 1 below:

Table 1: Examples of Display Specifications

		Ex.. 1	Ex.. 2	Ex.. 3	Ex.. 4	Ex.. 5	Ex.. 6
Typical Application		Appliance, cell phone	Classroom, lecture hall	Notebook computer	HDTV	Traffic sign	Sports arena
Resolution (P_C x P_H)		20 x 60	480 x 640	768 x 1068	1000x1500	96 x 192	600 x 800
No. of pixels in display		1200	307,200	820,224	1,500,000	18,432	480,000
Sq. Pixel Dimension	in mm	0.05 1.25	0.1 2.5	0.01 0.025	0.02 0.5	0.5 12.5	0.3 8
Overall Dimensions	in cm	1 x 3 2.5 x 7.5	48 x 64 120 x 160	7.7 x 10.7 19.2 x 21.4	20 x 30 50 x 75	48 x 96 120 x 240	180 x 240 450 x 600
R Refresh rate	Hz	30	30	60	60	30	30
P_G Pixel Charging Group		10	100	100	450	10	200
Maximum Column Charge Duration	μs	278	11	2	5	19	14

The proportions of rectangular pixels can be adjusted to optimize the electromechanical

known in the art, for example from Bozler 5,233,459, is that it be easily and inexpensively reproduced.

To this end, the drive circuitry system can be componentized, sourcing known subsystems as existing assemblies, especially as integrated circuits, or printed circuit boards, from component vendors, where possible. For example, suitable row and column driver inputs are available in integrated circuits comprising groups of fast-terminals and switches connectable with pixel rows or ITO columns, respectively, from vendors such as Supertex, Inc. Sunnyvale, California.

The embodiments of display illustrated in Figures 3 and 4 provide examples of low-cost monochrome displays according to the invention which could, alternatively, if desired, be rendered as full-color displays, at a higher cost, by incorporation of a suitable mosaicked color screen 24.

Referring to Figure 3, the display construction shown is suitable to provide a rugged, portable, bendable, low-cost, light-weight, shock–proof and vibration-proof reflective device particularly suited to field use, e.g for military, environmental and expedition use, or for portable video games or game players, and so on.

The layers shown comprise a thin-panel back plate 150 formed essentially of aluminum, optionally strengthened with a backing layer of plastic reinforcement 152 to strengthen protect aluminum back plate 150 inexpensively. The aluminum back plate 150 is both electrically conductive, providing part of a Faraday cage to protect the display from static fields, and optically reflective reflecting light entering through cover 52, to illuminate the raster. Electrically conductive vertical columns 154 of fixed or control electrodes can be inexpensively provided (current cost about one penny per square foot) employing a suitably patterned film of a metallized polyester bonded to the aluminum back plate 150, with the insulating side to the back plate preventing columns 154 from shorting out through the aluminum back plate 150. Though various other constructions are possible, such as die-cutting electrode patterns through the full thickness of the metallized polyester film, it is preferred that the electrode pattern be applied only to the metallization, for example by photolithographic etching.

The layer of columns 154 can be heat-bonded to a polypropylene or other transparent dielectric

the viewer side of dielectric 32, the rows of spiral rollouts 20 are mechanically and electrically attached to dielectric 32. Each spiral rollout 20 serves as a shutter which progressively covers or uncovers a pixel area on the raster. The pixels are separated from the front window glass or LUCITE 52 by a space of about 3/32 inches or more, depending on dimensions.

Light from illumination 158 travels through the glass substrate 160, columns 162 of fixed electrodes, dielectric 32 and through any open, (shutter retracted) pixel, presenting a white or light appearance to the viewer which will contrast with the black or other low intensity appearance of any extended spiral rollouts 20. Ambient light, enters in the direction of view and is reflected off glass substrate 160, presenting a white appearance, if ambient light levels are strong enough.

Illumination 158 may be user activated, or always on when the display is powered, or, especially for portable applications where power management is at a premium, illumination 158 may be controlled by a light sensor (not shown) to be activated at lower light levels.

Shaped and Flexible Embodiments

A particular advantage of the novel thin-panel video display technology described herein, and in the parent patents and application, is that the capacitive pixels do not have to be constrained to planar configurations but can be deployed in a variety of shaped displays. More particularly, because the functional components of the pixel elements can be embodied in polymer film materials, suitably shaped and treated polyester, polypropylene and the like, novel flexible, folded and shaped displays can be provided in forms such as books, fanfolds, scrolls and panoramas, such as shown in Figures 5, 6, 7 and 8, respectively. Variable form devices such as those of Figures 5-7, are compact for storage but can open up to a display area which is larger than any projected area or footprint the device may have during in storage. Thus, for example, a generally rectangular, pocket-book sized, bi-fold device may have overall dimensions of approximately 8 inches by 4 inches (approximately 20 cm by 10 cm), while folded, and open up to provide a rectangular display having a diagonal dimension of 9 or more inches (approximately 22.5 cm) extending across both leaves of the bifold, for example approximately 8 inches by 5 inches (approximately 20 cm by 12.5 cm).

The device shown in Figure 5, which could for example be a pocket or notebook computer,

The housing structure may also be flexible or shaped according to the configuration of the display, or may have a fixed, box-like shape to accommodate a folded or rolled up display in an out of use configuration. Other flexible, foldable or shaped, or shaped and flexible, thin-panel display structures, employing flexible film materials, but using different pixel technology will be apparent to those skilled in the art. For example, a portable video presentation device, e.g. a computer, may comprise a notebook style, hinged two–leaf construction device, one leaf of which has multiple panels, e.g. four or six panels, that can be unfolded to provide an extended display area for presentations and can be folded into a compact volume, e.g. with the form of a single panel, for portability.

Seams, hinges, or other high stress or highly curved structure within the display area may or may not include operative pixels, for example a small number of columns of pixels in a vertical fold application may be by-passed by conductors or their addresses may be interpreted as non-existent by software drivers, or the display may be a composite display of physically separated panels of pixels, the panels cooperating to provide the desired image and functioning together as an integral display. If desired to facilitate construction, small margins between the panels may be passive, non-pixellated structures.

As a further protection against electrostatic interference, the electrostatic displays of the invention, or prior art electrostatic displays, can be housed in a Faraday cage by rendering conductive any non-metallic enclosing surfaces around the display, by using conductive plastics material for relevant opaque housing elements that surround or enclose the active display raster, or by coating or impregnating them with conductive material. Those skilled in the art can of course consider such transparent conductive materials, and any other transparent conductive materials, as they are known or become known from time to time, for use in the practice of the present invention, or the inventions of the parent patents, as alternatives to indium tin oxide where a transparent fixed electrode, or other transparent conductive structure, is desired.

Manufacturing Methods

As stated hereinabove, and in patent 5,519,565, the inventive displays disclosed herein and in the parent application and patents, are adapted to low-cost mass production methods. In particular, continuous film techniques may be used to provide matrix layer 18 of movable electrodes 20 assembled with dielectric layer 32 and, optionally, with a flexible substrate.

connectors, that can mate with the display's edge connectors.

Further Display Embodiments

The economy and slim profile of the display systems described herein, and in the parent applications, permit a variety of new and advantageous configurations of displays. Some examples of such novel displays will be described below, and others will be apparent to those of ordinary skill in the art.

In addition to conventional size television or computer monitors having a diagonal dimension in the range of from about 6 to about 25 inches (about 15 to about 63 cm), relatively large wall-mounted displays for theater or group viewing provide a particularly advantageous configuration. Such displays can have a diagonal dimension in the range of from about 30 to about 180 inches (about 75 to about 450 cm) although even larger displays may be constructed for special purposes such as outdoor events, concerts and the like. However, a preferred size is in the range of from about 50 to about 100 inches (about 125 to about 250 cm)

Such larger thin-panel display systems according to the invention are lightweight and can readily be wall-mounted, or depend downwardly from a support, or both, with minimal need for any but the simplest support structures such as one or more latches or hooks, or equivalent mechanical structure or even hook-and-loop type fastening means distributed over the rear surface of the display system and complementary wall area. Alternatively, the displays could be built-in. Regardless of the mounting means, such larger configurations of the inventive displays are suitable for use in the home, in the office, for military use or for entertainment or educational use, or wherever there is a need for a large screen displaying a large image.

In such larger configurations, the inventive display provides the advantages of good angular viewability, excellent contrast, bright colors, daylight visibility and, in particular, direct viewing, meaning that the image is created on or at the display itself, not elsewhere. The display accordingly lacks the drawbacks of projected images which require a darkened room and are subject to interruption by individuals moving between the projector and the screen, as is the case, for example, in conventional movie theaters. Thus, a still further application of the invention is to replace conventional movie screens with an electrostatic pixel display screen, pursuant to the invention, providing a new theater experience employing the sharpness and

As shown in Figure 11, alternative or additional peripheral equipment which can be used includes an input device 268 for one, or more, or each member of the audience. Input device 268 may be as simple as a switch, or impulse generator, enabling the audience member to vote or provide other binary input directly to a control computer system 270 driving the display 250, for immediate or delayed onscreen display of audience input, while an instructor or conference leader continues their presentation. With each audience member so equipped, the audience can vote their opinions on the displayed material visually, while the presentation is in progress, without audibly interrupting the speaker, enabling the speaker to take in the audience consensus while speaking. Alternatively, the votes can be collected for display during a recess in the presentation, if desired.

More sophisticated input devices 268, e.g. pointing devices such as a mouse, keyboard, or drafting tablet, or even microphones can be provided, if desired, enabling the audience to write or draw directly to the display screen or otherwise provide input to the display system which can be selectively output onscreen, depending upon the software or other available controls. Also, an input controller 272 and voice recognition means, if desired, can be provided either centrally at the control computer 270 or in conjunction with a local override switch, at one or more of the audience input devices 268, to determine which input device or devices 268 is active at any given moment and, optionally an indicator, which may be alphanumeric, of the active device can be displayed onscreen.

Monochrome embodiments of the invention lend themselves to uses for signage bringing excellent viewability and low-cost to replacement of conventional cathode ray tubes in products such as airport, train and bus arrival and departure display monitors. Such displays, when used in this embodiment can have diagonal dimensions comparable to current CRT displays, namely from about 10 to about 18 inches (about 25-45 cm), with electrostatic pixel widths in the range of about 0.05-0.2 inches (about 0.1-1 cm), preferably of the order of about 0.1 inches (0.2- 0.3 cm), providing excellent resolution. The implicit low cost of materials and manufacturability of the displays of the invention may enable larger displays than have heretofore been customary to be economically deployed for such purposes.

Reflective embodiments or "transflective" embodiments, can be provided with excellent contrast providing superior visibility in the bright light of airport and comparable environments. Such larger display embodiments of the invention can be used for road signs or main arrival and

being shown as white squares.)

The display 280 can be incorporated in a weatherproof, mountable housing 288 mounted on a pedestal 289, or other support and accommodating desired drive circuitry 290, data processing 292 and a power supply 294, which depending upon the intended location of deployment of the display 280 may plug in to a local power supply network, be battery-powered, or include a standby battery 296 activated by switch 297 in response to failure of power supply 294. If desired, a solar panel 298 can be mounted on top of the display 280, or at another appropriate location to be used in conjunction with a battery which stores solar energy collected during the day to power the sign at night. While solar panel 298 can reduce power costs, a supplemental power source will probably also be needed to maintain continuous operation of the display. The unique, low power requirements of the inventive displays facilitate provision of a suitable power supply.

If desired, an optical sensor 300 can be provided to switch the display 280's background illumination on and off according to ambient light levels, or to switch the power supply 294 between modes, or both.

Preferably also, an external communication device, for example a modem 302, is provided along with a telephone line, dedicated line or cellular airwave connection to telephone network 304 to enable remote programming or writing of messages for display.

The invention is capable of wide application, and in addition to the above-described embodiments, can be used for applications currently fulfilled with liquid crystal display ("LCD") technology for example pocket computers, calculators, cellular phones, pagers and other information appliances as these evolve, as well as the present-day large field of laptop and notebook computers. As will be apparent from the teachings herein, the invention is well suited to provide lightweight, portable, affordable, shatterproof, hand-held displays for military and other uses.

Peripheral Equipment

In addition to the display raster and drive circuitry that have been described in some detail herein, along with certain housing features, the displays of this invention and of the parent

desirable, then a sealed or a hermetically sealed system may be justified, and scrupulous cleanliness should be observed in the manufacture of the pixel array, especially with regard to the rollout surfaces.

Energy-saving devices can be provided to reduce or switch off the power supply under specified conditions such as a lack of user input or lack of change in the display in a given time interval.

Manually indexable knobs, buttons or slider controls can be provided, as desired, for user adjustment of features such as brightness, contrast, color intensity and hue but, unlike conventional cathode ray tube displays, image positioning and shaping controls will probably not be necessary in most applications.

Data-processing, or signal processing and tuning devices, can be provided in a common housing with the display, or in pluggable, or otherwise connectable, associated units, as is known in the art or arts.

It will be understood that while the novel drive circuitry described in this application is preferred for use in the various embodiments of electrostatic pixel display described in this application, in the parent application and in the parent patents, nevertheless, other embodiments of drive circuitry may be employed in such displays, as will be apparent to those skilled in the art, or as may become apparent through developments made subsequently to the present invention.

Display Applications

Displays according to the invention can serve a wide range of uses, providing for example: wall video; motion picture theaters where a live signal received by telephone cable is "projected" live onto the screen; portable picture video entertainment; instrument image devices capable of showing graphs, etc; heads up imaging for vehicular or training communication; dashboard (automotive); dashboard (airplane); signs, POS, interactive; scoreboards (stadium); shop windows (big city); used car lot; indoor stadium (basketball, tennis, swimming); convention center message center or information board; window blind with solar sensor; electronic curtains (for example remotely or locally controllable to choose different fabric appearances,); greenhouse shades (automatically admit proper light for plants); window blinds (privacy or radiation monitor or lace pattern); clocks for telling time, and for advertising; educational

Claims

1. An electrostatic display having drive circuitry comprising:

a) an array of pixels (A1...F5) each including a capacitively drivable shutter electrode (20) movable between an open, light-transmitting position and a closed, light-blocking position; and

b) drive circuitry for the pixel array capable of applying control signals to selected pixels (A1...F5) to move selected individual ones of the electrode shutters between their respective open and closed positions;

characterized in that the drive circuitry is operable to charge each selected pixel (B3) in a relatively short charging interval and to discharge each selected pixel (B3) in a relatively longer discharging interval.

2. A display according to claim 1 **characterized in that** the movable electrode (20) is mechanically biased to return to a starting position whereby no negative pulse is required to retract the electrode (20).

3. A display according to claim 1, or 2 **characterized in that** the ratio of the discharging interval to the charging interval is at least 5:1 or is at least 500:1.

4. A display according to claim 1 **characterized in that** the drive circuitry effects charging by applying a short charging pulse to one or more pixels (A1...F5) to be charged, the charging pulse having a pulse width determining the charging interval.

5. A display according to claim 1, 2, or 4 **characterized in that** the charging pulse is applied to a dumping capacitor (110) servicing a group of pixels (A1...F5) and the dumping capacitor (110) is connected to charge each and every specified pixel in the pixel group on each refresh cycle.

6. A display according to claim 1 **characterized in that** the drive circuitry further includes a number of bleed resistances (120) for draining charge from the pixels (A1...F5) and each pixel is connected with one of said bleed resistances (120) to drain charge therefrom.

7. A display according to claim 1,2, 4 or 6 **characterized in that** the value of each bleed resistance (120) is selected, in relation to the capacitance characteristics of the pixel, to

14. A display according to claim 9 **characterized in that** the drive circuitry includes a power source and, for each row of pixels (A1...F5), a clock switch to connect the row to the power source (130) .

15. A display according to claim 9 or 14 **characterized in that** a row dumping capacitor (110) is connected to each row of the raster to receive charging pulses from the drive circuitry and discharge to specified pixels (A1...F5) in the row and a radio frequency choke (122) is provided for each pixel row to inhibit drive pulses from traveling in an unintended row, each row of pixels (A1...F5) is supplied with a biasing d. c. voltage to a value below a pixel activation threshold, each pixel comprises a movable electrode and a fixed electrode (22) and each movable electrode (20) is connected to the drive circuitry through a bleed resistance (120) to delay bleed-off of charge from the pixel.

16. A display according to claim 9 **characterized in that** each pixel comprises a movable electrode (20) and a fixed electrode (22), the movable electrodes (20) of each row of pixels (A1...F5) being interconnected, the fixed electrodes (22) are connected in columns extending transversely of the pixel rows and the drive circuitry further includes a column dumping capacitor (108) for each column of pixels (A1...F5).

17. A display according to claim 9 **characterized in that** the drive circuitry includes a power source (130) and, for each column (A-F) of pixels a clock switch (104) to connect the column to the power source (130).

18. A display according to claim 17 **characterized in that** the drive circuitry comprises a drain resistor for each column of pixels (A1...F5) connected in parallel across the column dumping capacitor (108) to leak charge across the dumping capacitor (108)and drain static build up.

19. A display according to claim 18 **characterized in that** the drive circuitry includes:

a) a power source (130) and, for each row of pixels (A1...F5), a clock switch (117) to connect the row to the power source (130);

b) a row dumping capacitor (110) connected to each row of the raster to receive charging pulses from the drive circuitry and discharge to specified pixels (A1...F5) in the row; and

c) and a radio frequency choke (122) for each pixel row to inhibit drive pulses from

i) a drain resistor for each column of pixels (A1...F5) connected in parallel across the column dumping capacitor (108) to leak charge across the dumping capacitor and drain static build up.

23. A display according to claim 22 **characterized by** comprising a housing for the display, the housing providing a Faraday cage (60-62) enclosing the display and shielding the display from electrostatic interference.

24. A display according to claim 21 **characterized by** being configured as a thin, flat panel computer, information appliance, television or indicator display.

25. A rasterized electronic display having an array of pixels (A1...F5) each comprising a dielectric element and an electrostatically movable, light-modulating electrode movable into contact with the dielectric element and having an area of contact with the dielectric, **characterized in that** each individual pixel comprises a Faraday cage (60-62) extending around the area of contact to shield the movable electrode (20) and control leakage of charge from the pixel.

26. A display according to claim 25 **characterized in that** each pixel comprises a fixed electrode (22) opposed to the movable electrode (20) across the dielectric element and **in that** the fixed electrode (22) is larger than the area of contact of the movable electrode (20) and provides a marginal zone around the periphery of the area of contact.

27. A display according to claim 25 or 26 **characterized in that** the movable electrode (20) comprises a spiral rollout having a rectangular shape when extended and the fixed electrode (22) has a corresponding rectangular shape and larger size providing lateral extensions on all four sides of the rollout whereby all four sides of the rollout are shielded.

28. A thin panel video display **characterized by** being non-planar and flexible, or foldable, or shaped, or flexible and shaped.

29. A thin panel video display according to claim 28 **characterized by** comprising a display raster of electrostatic pixels (A1...F5).

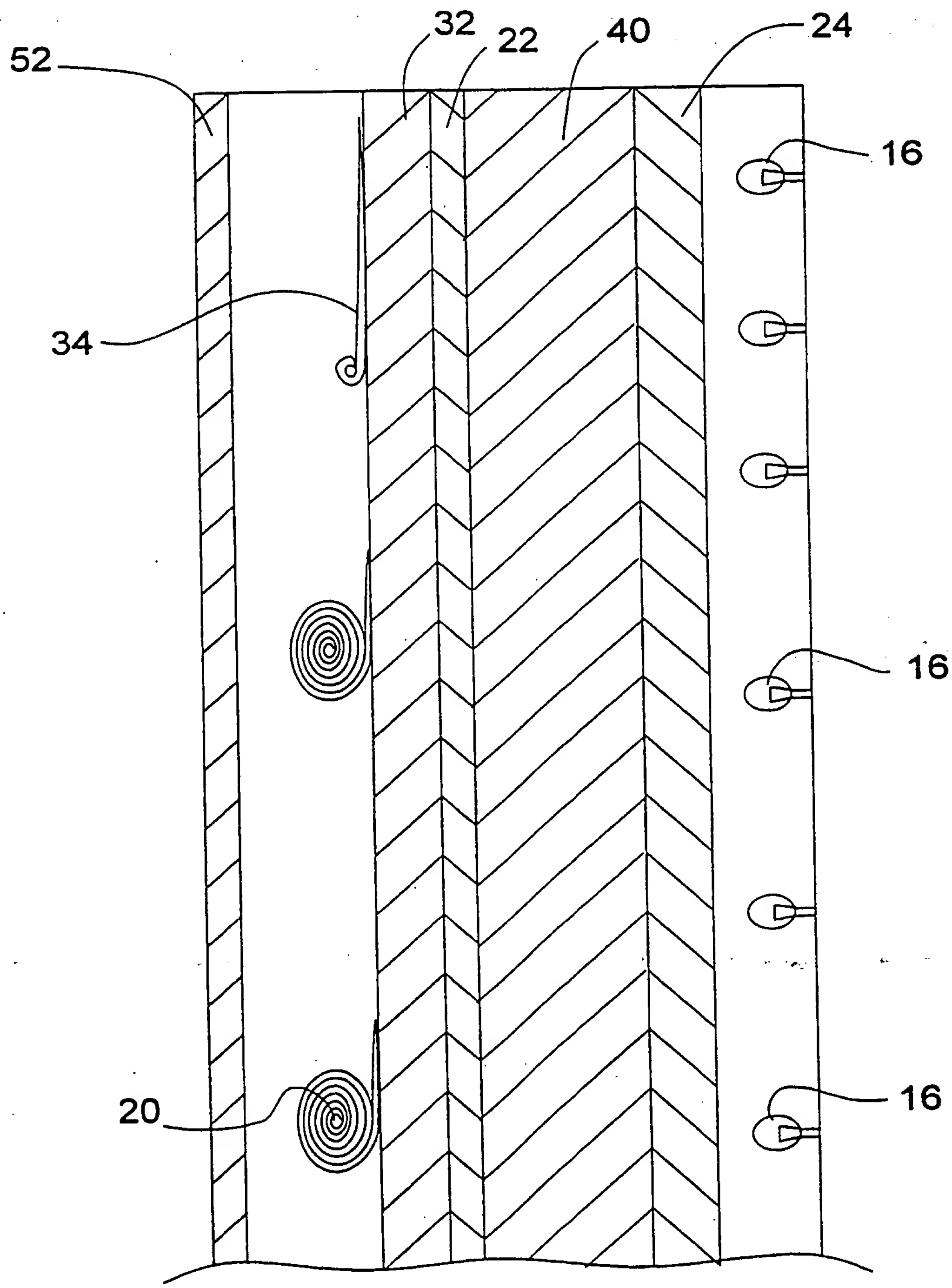


FIGURE 1

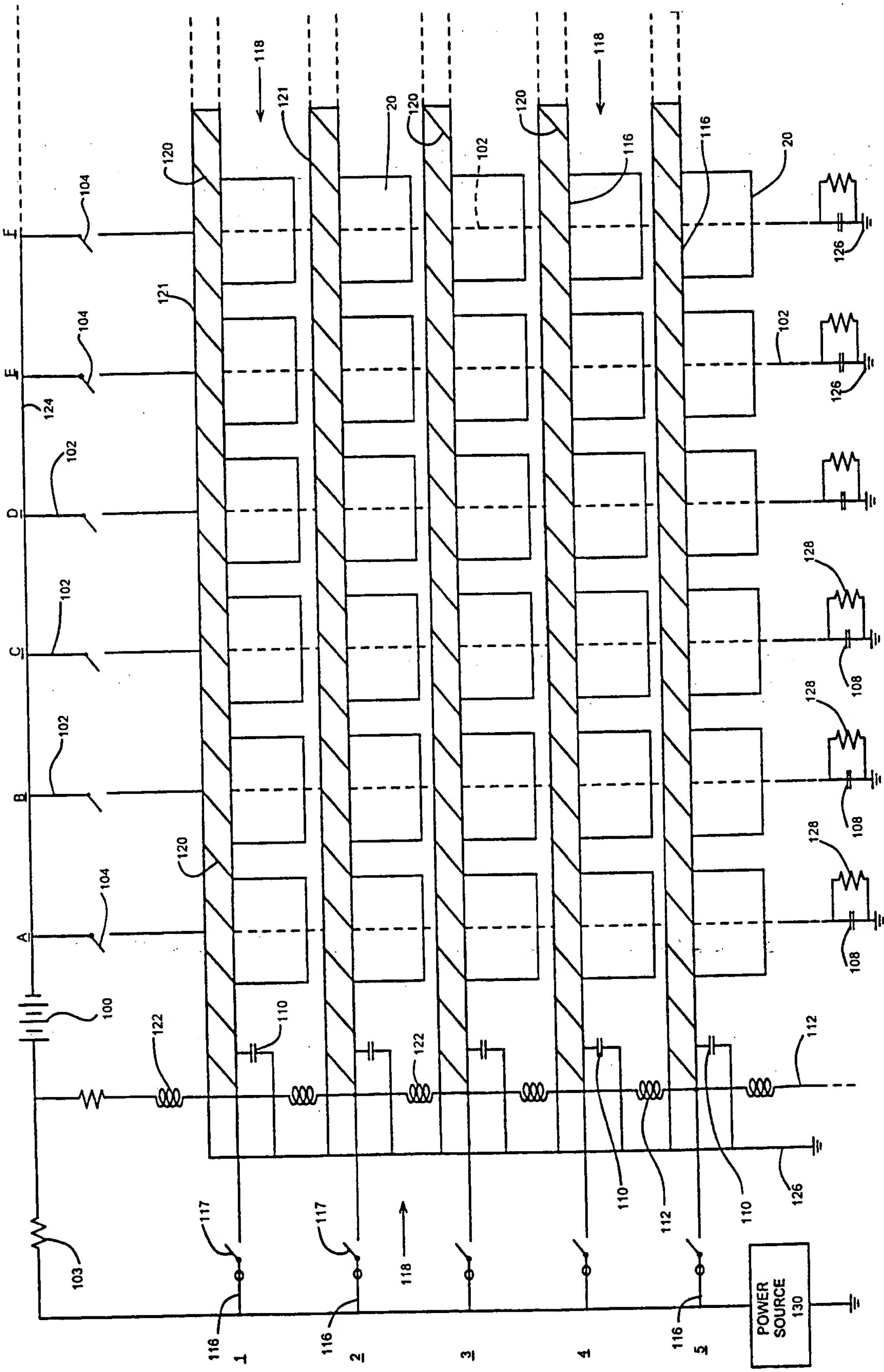

A
B
C
D
E
F
1
2
3
4
5
POWER SOURCE 130
20
100
102
103
104
108
110
112
116
117
118
120
121
122
124
126
128

FIGURE 2

FIGURE 2A

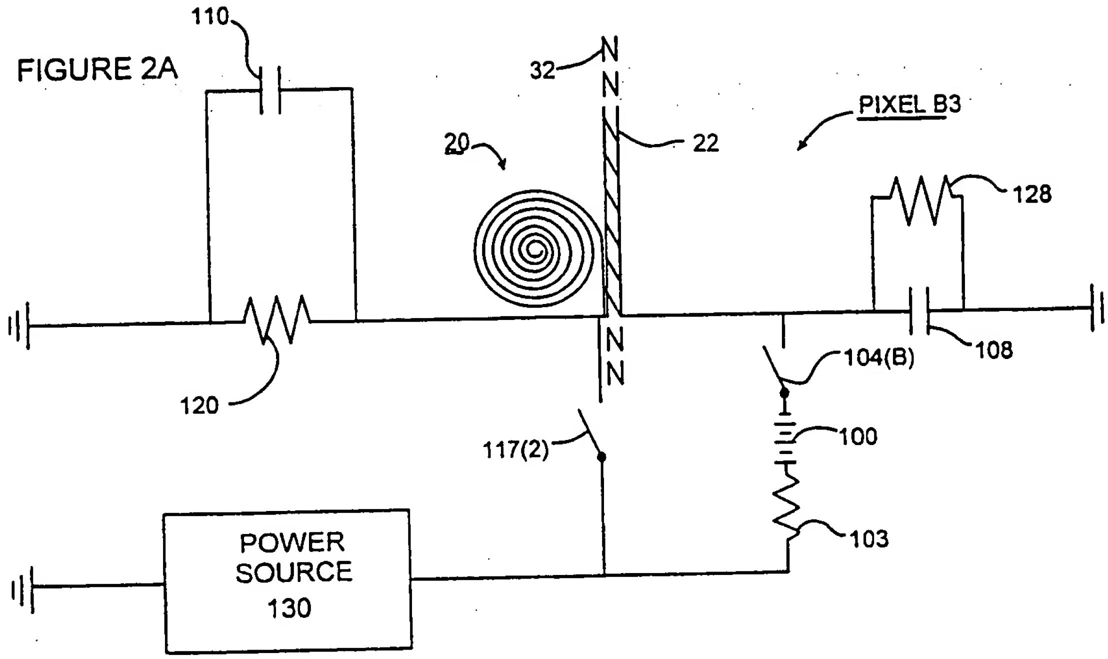


FIGURE 2B

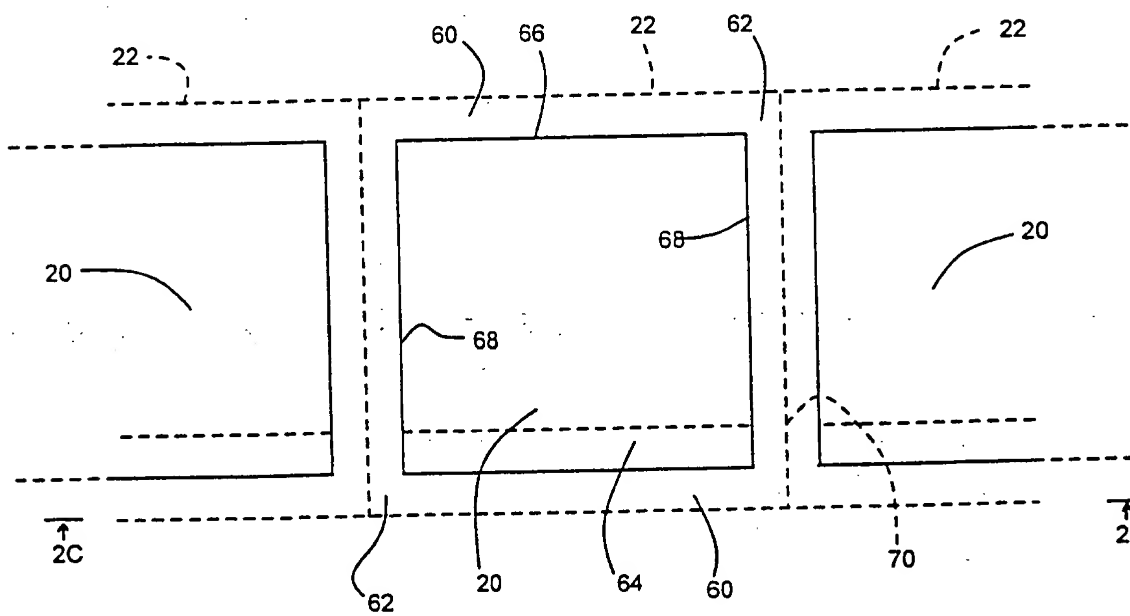
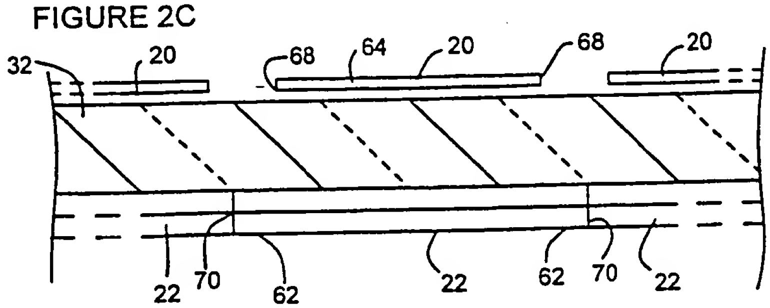


FIGURE 2C



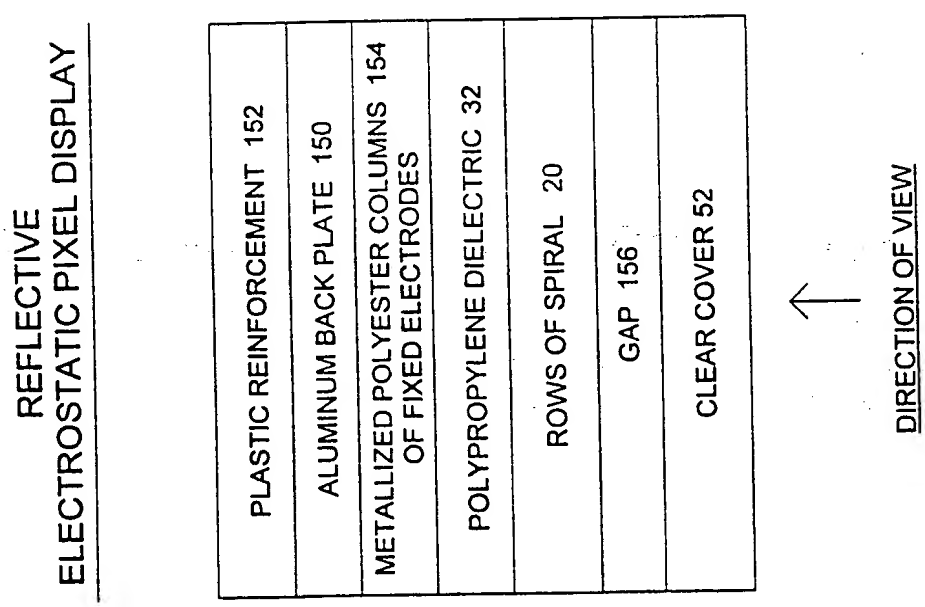


Figure 3

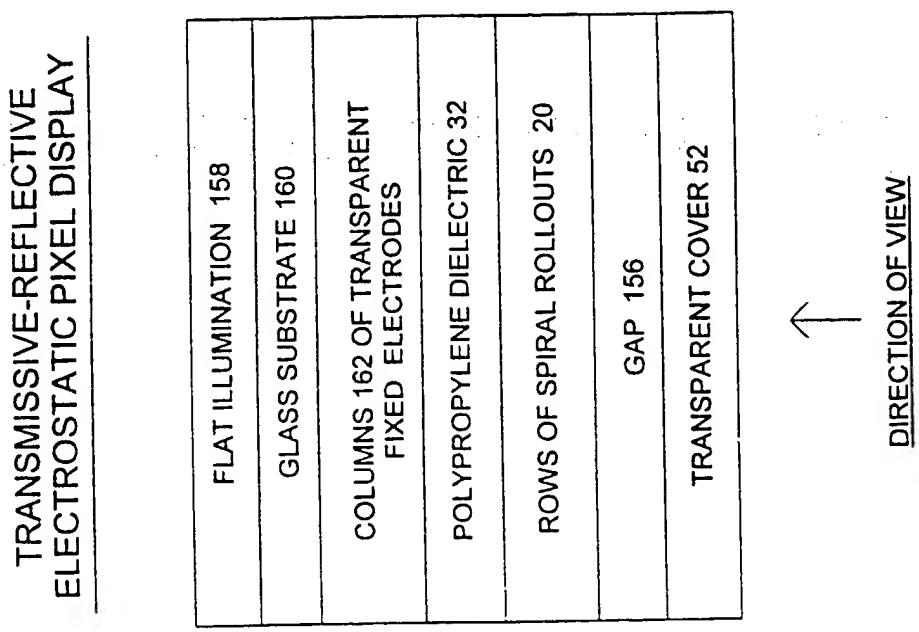


Figure 4

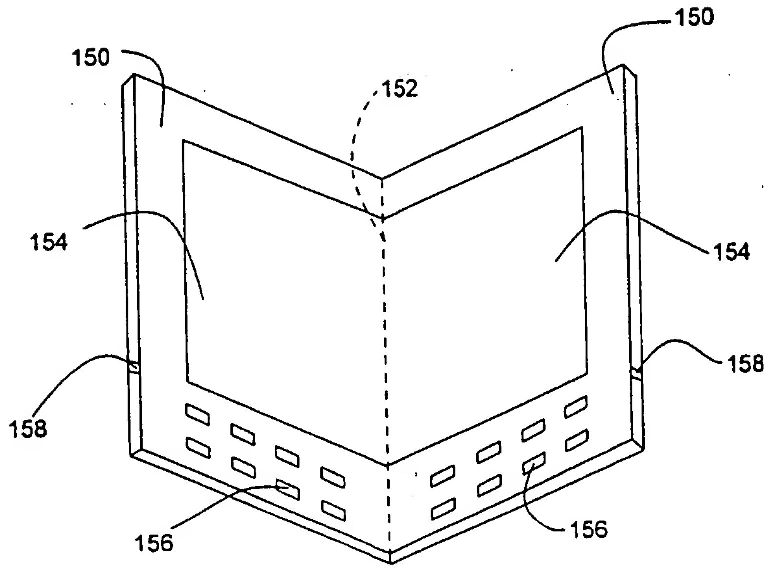
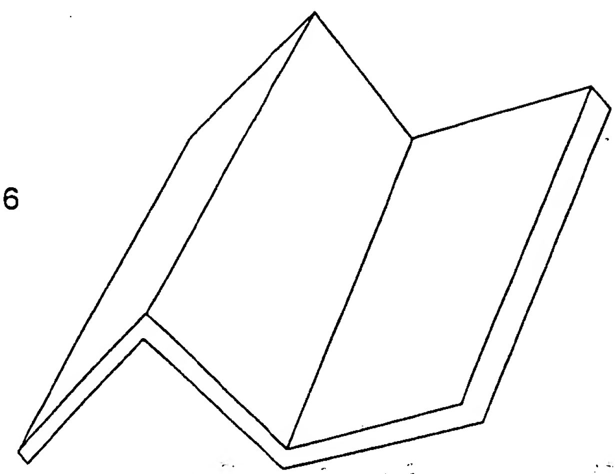


FIGURE 5

FIGURE 6



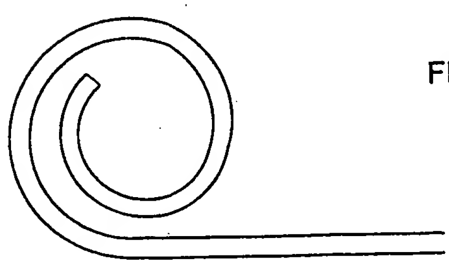
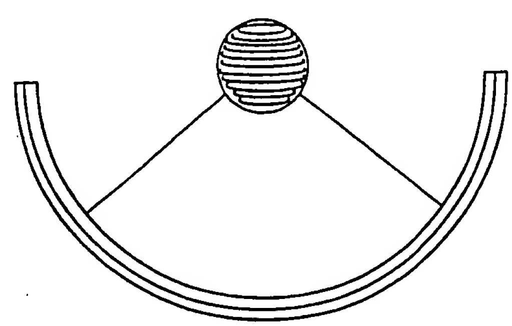


FIGURE 7

FIGURE 8



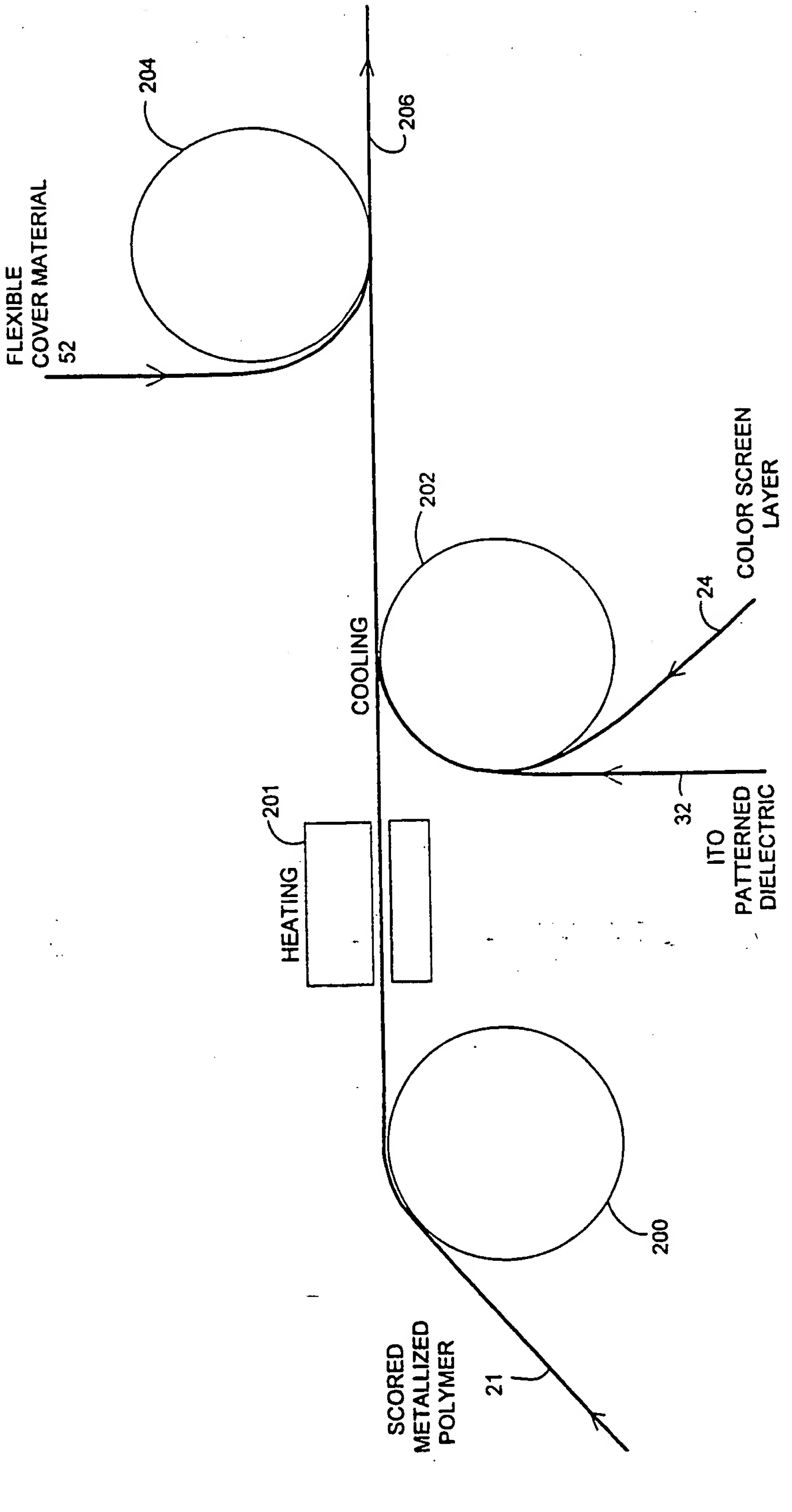

FLEXIBLE
COVER MATERIAL
52
204
206
202
COLOR SCREEN
LAYER
24
COOLING
201
HEATING
32
ITO
PATTERNED
DIELECTRIC
200
21
SCORED
METALLIZED
POLYMER

FIGURE 9

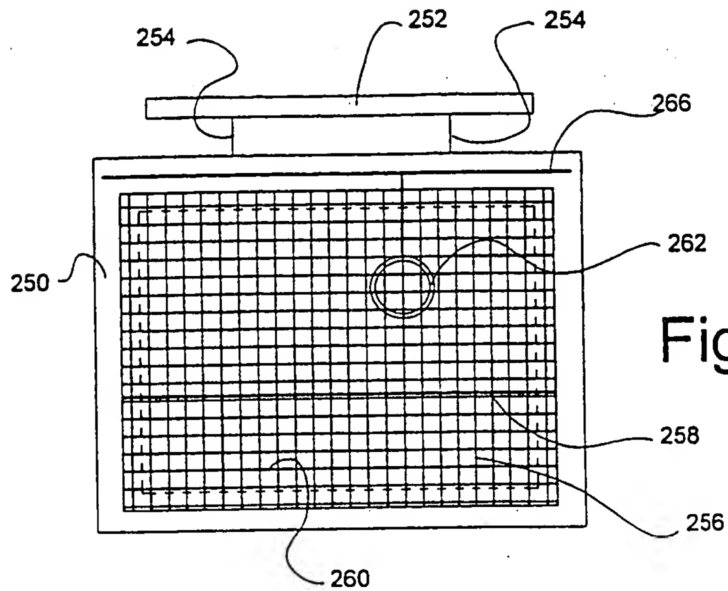


Figure 10

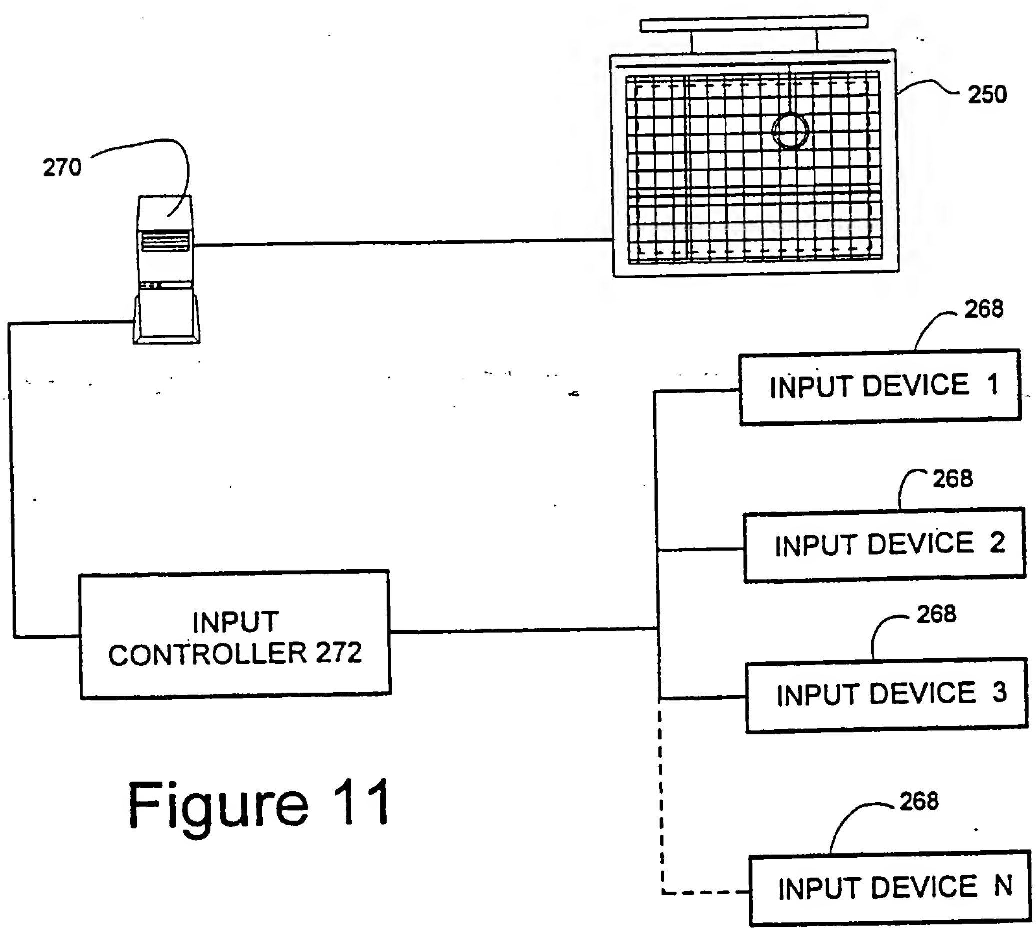


Figure 11

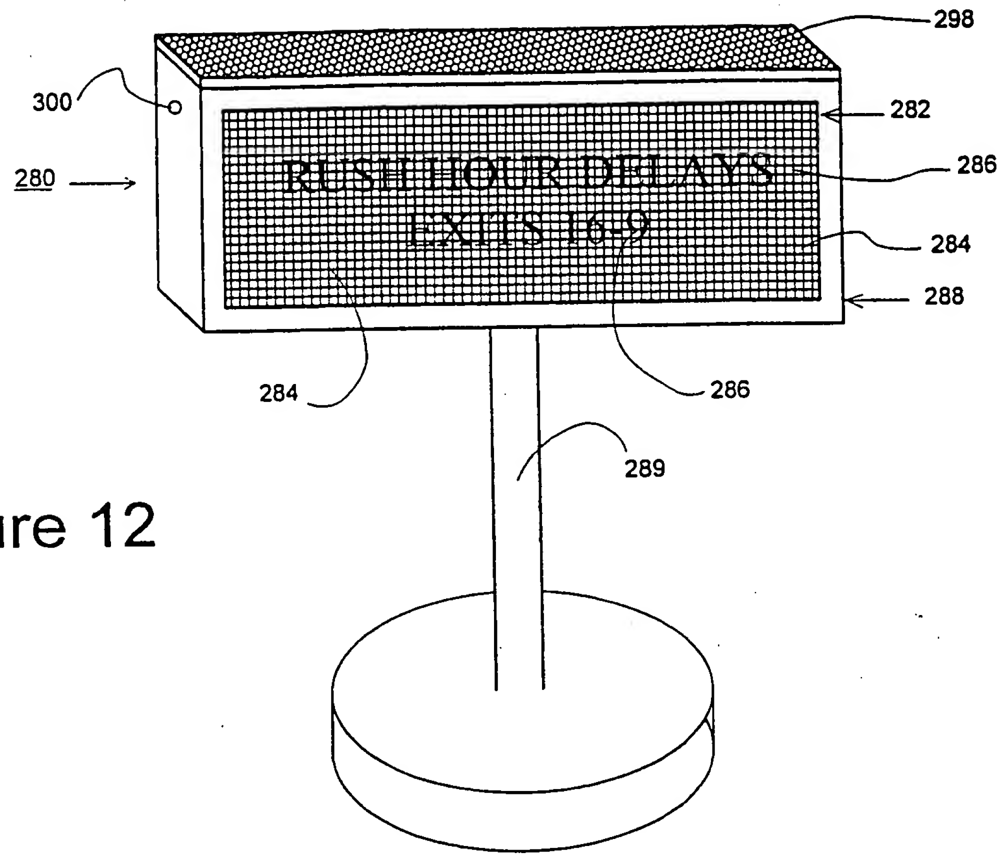


Figure 12

Figure 13